Pressure Analysis for LAVA-OVEN

Donna Q. Cendana
NASA Kennedy Space Center
Major: Bachelor of Science in Mechanical Engineering

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Pressure Analysis for LAVA and OVEN

Donna Q. Cendana[1]
The City College of New York, City University of New York, New York, NY, 10031

The Lunar Advanced Volatiles Analysis (LAVA) and the Oxygen & Volatiles Extraction Node (OVEN) are subsystems included in the Regolith & Environment Science, and Oxygen & Lunar Volatiles Extraction (RESOLVE) payload bound for the Moon in 2019. This Resource Prospector Mission (RPM) has the objective of landing on a shadowed region of the Moon's South Pole to collect data and determine whether the resources could be effectively used for space exploration systems. The quantification of the resources will help understand if it can adequately minimize materials carried from Earth by: providing life support, propellants, construction materials and supply energy to the payload or crew. This paper outlines the procedures done for the pressure analysis of the LAVA-OVEN (LOVEN) Integration Testing. The pressure analysis quantifies how much gases and water are present in the sample tested during the Engineering Testing Unit (ETU) phase of instrument development. Ultimately, the purpose of these tests is to improve the estimate of the amount of water in each Lunar sample and reduce the time necessary for this estimate. The governing principle that was used for the analysis is the Ideal Gas Law, PV=nRT, where P stands for pressure, V for volume, n for number of moles, R being the gas constant and T for temperature. We also estimate the errors involved in these measured and derived quantities since a key objective of the mission is to estimate the quantity of volatiles present in the lunar samples introduced into OVEN.

Nomenclature

°C	=	Degree Celsius
atm	=	atmospheres (pressure SI unit)
cm^3	=	cubic centimeter (volume SI unit)
ETU	=	Engineering Test Unit
FSS	=	Fluid Subsystem
FPV00#P	=	MSID Label for Pressure Transducer # (F=Fluid System Instrument, P=Pressure Sensor End Item Class, V=Telemetry Instrumentation or Command Point, 00#=End Item Serial Number, P=Pressure Engineering Unit type)
FTV00#T	=	MSID Label for Resistive Temperature Detector # (F=Fluid System Instrument, T=Temperature Sensor End Item Class, V=Telemetry Instrumentation or Command Point, 00#=End Item Serial Number, T=Temperature Engineering Unit type)
g	=	grams (mass unit)
GC	=	Gas Chromatograph
GC-MS	=	Gas Chromatograph-Mass Spectrometer
HTR – 0##	=	Heater – numerical location signifier
ISOLAT – 0##	=	Isolation Valve – numerical location signifier
ISRU	=	In-Situ Resource Utilization
K	=	Kelvins (temperature SI unit)
LAVA	=	Lunar Advanced Volatiles Analysis
mol	=	moles (number of moles unit)
MS	=	Mass Spectrometer
n	=	number of moles
NASA	=	National Aeronautics and Space Administration
NIRVSS	=	Near-Infrared Volatile Spectrometer Subsytem
NIRST	=	Near-Infrared Spectrometer for the Surge Tank

[1] Intern, Engineering and Technology Directorate, Materials Science Division, Applied Physics Lab, NASA Kennedy Space Center

NSS	=	Neutron Spectrometer Subsystem
OBR	=	On-Board Recording
OVEN	=	Oxygen & Volatiles Extraction Node
P	=	Pressure
PS – 0##	=	Power Supply – numerical location signifier
PT – 0##	=	Pressure Transducer – numerical location signifier
R	=	Gas Constant
RESOLVE	=	Regolith & Environment Science, and Oxygen & Lunar Volatiles Extraction
RPM	=	Resource Prospector Mission
RTD or RTDs	=	Resistive Temperature Detector or Detectors
SATS	=	Sample Acquisition and Transfer System
ST	=	Surge Tank
T	=	Temperature
TEC	=	Thermal Electric Cooler
TSE	=	Test Support Equipment
V	=	Volume
VLAT – ###	=	Latching Valve – numerical location signifier
WDD	=	Water Droplet Demonstration
WOA	=	Work Order Authorization
xGDS	=	Ground Data System, Data archive retrieval exploration

I. Introduction

For a very long time, scientists argued whether water ice exists on the lunar surface. Then, it was discovered that there are potentially substantial hydrogen rich resources on the Moon[2]. However, the amount of the water on the surface, its distribution, and its viability as a resource for human exploration systems are still in question. To answer these questions, NASA is developing a payload termed RESOLVE. The RESOLVE system consists of a rover-mounted payload (shown in Fig. 1), which comprises various prospecting instruments: Neutron Spectrometer System (NSS) locates areas of high hydrogen concentration to ensure that an appropriate sample of the regolith is being collected, Near-Infrared Volatile Spectrometer Subsytem (NIRVSS) assists prospecting by identifying any surface volatiles and providing mineralogical context, Sample Acquisition and Transfer System (SATS) acquires a one-meter deep sample of regolith by drilling, Oxygen & Volatiles Extraction Node (OVEN) which consists of a reactor subsystem that will gradually heat samples collected by the SATS to 150°*C* and the Lunar Advanced Volatiles Analysis (LAVA) which identifies and quantifies gases evolved from samples heated in the OVEN. The RESOLVE Ground Demonstration Unit was assembled and integrated on a rover platform for a field demonstration and testing shown in Fig. 2. The testing was done at a lunar analog site on the slopes of Mauna Kea in Hawaii in the summer of 2012 and will do another Resource Prospector Integrated Testing for the fiscal year of 2015. By 2016, the RESOLVE design team will begin hardware flight certification tests. A launch of the RESOLVE system is planned for a May-June time frame in 2019 or 2020, depending on the capability for delivery of a lunar payload.[3]

In the LAVA subsystem, volatiles evolved in the OVEN travel through the Fluid Subsystem (FSS) to several instruments. The sample may be stored in the surge tank, where it can be analyzed by the Near-Infrared Spectrometer for the Surge Tank (NIRST) or go directly to the Sample Delivery System (SDS) to be analyzed by the Gas Chromatograph-Mass Spectrometer (GC-MS). If there is enough water, the sample may be transferred to the Water Droplet Demonstration (WDD), a "cold finger", where the vapor would condense and form a droplet of water to give a visual evidence of the sample collected. The most important goal of LAVA is to determine the percentage of water by weight in the lunar sample. Secondary objectives include identifying other volatile components. This document addresses tests to quantify the ability to estimate the amount of evolved gases in the OVEN using the perfect gas law and on board temperature and pressure measurements. This total would be combined with NIRST or GC measurements to estimate the total water content.

[2] EPSC Abstracts, Vol. 6, EPSC-DPS2011-PRVIEW, 2011
[3] NASA's Kennedy Space Center, volume 5, number 11, spring/summer 2012

Figure 1. RESOLVE Rover with mounted payload. A computer aided design (CAD) model of RESOLVE.

Figure 2. RESOLVE Rover with mounted payload. RESOLVE on a Field Demonstration Unit (FDU) in Hawaii on

The LAVA subsytem is now integrated with the OVEN reactor and is referred to as 'LOVEN' in the text that follows. Testing was done in a thermal vacuum chamber, simulating the lunar environment. The analysis of the data collected from the test is the main content of this paper. The goal is to demonstrate the reliability of the instruments and certify that they meet the mission objectives. The complicated design of the LAVA subsytem challenged the team to find anomalies, fix the problems, and improve the design of the system to make it ready for flight.

II. Background for the LAVA-OVEN Testing

First, the Resource Prospector is going to land at the Lunar South Pole. A rover-mounted instrument suite will be transported around this permanently very shadowed region of the moon where the water ice is expected to be present. Once a surface concentration of water is found, the drilling and sample extraction would be performed. The SATS would drill a meter deep in 10 centimeters increments until a sample regolith with abundant source is detected. The drill will deposit this regolith sample in the OVEN and will heat the sample driving off volatiles. One of the key mission objectives is to estimate the percentage of water by mass in each sample. This is accomplished by first weighing the sample then by analyzing the total amount of water volatized. Since there are expected to be a wide variety of volatile compounds, two candidate instruments, a Gas Chromatograph/Mass Spectrometer and a near infrared spectrometer are used to measure the percentage of water in the volatized samples. The total mass of volatile gases is estimated using the perfect gas law applied to each batch gas transfer until the sample (OVEN) pressure drops to some predetermined level and no more vapor is being produced. The mass of vapor remaining in the oven is then estimated. To perform these estimates, the team developed 'pressure volume testing' which is the subject of this paper.

The purpose of the pressure volume testing is to develop and verify techniques for estimating the quantity of volatiles in the OVEN based on measurements of temperatures and pressures during transfers from the OVEN to the Surge Tank and to test an additional concept where the free volume of OVEN is estimated (the geometric volume of empty oven minus the displaced volume of the non-volatile residual soil). If successful, these provide a means to greatly improve the accuracy of the estimate of the mass of volatiles in each sample and decrease processing time per sample.

In this ETU ground testing, the OVEN and LAVA are prepared prior to each test with a known quantity of either water or wet regolith simulant in the OVEN. The LAVA-OVEN (LOVEN) is then sealed within the vacuum chamber and pumped down to 10^{-5} Torr, nominal to simulate lunar operations. The testing described herein takes place from this point forward, when a sample is already in the OVEN and ready for analyses. The LAVA ETU Startup procedure has been completed prior to the beginning of these tests.

The LOVEN Full Procedure can now be started by running the Virtual Machine Language (VML), an automated software sequence integrated to LabView made for the batch transfer to initiate the LOVEN Science Manager. From here, VML does all the commanding for the valves unless prompted for a pause in the sequence to allow manual data recording. The steps made by the VML software can be monitored on the LAVA Interface Software Display and the System Messages tab for the VML status and user prompts. VML will close all latching valves (VLATs) upon activating the software. Next, the LAVA system is evacuated by VML opening VLAT-009 and VLAT-010 for 2 minutes; then close those valves again. This ensures that the initial pressure of the ST is zero. (VLAT-009 is the ST Line B water droplet bypass valve and VLAT-010 is an unrestricted vent-latching valve. These can be seen in the schematic diagram in Fig. 3.).

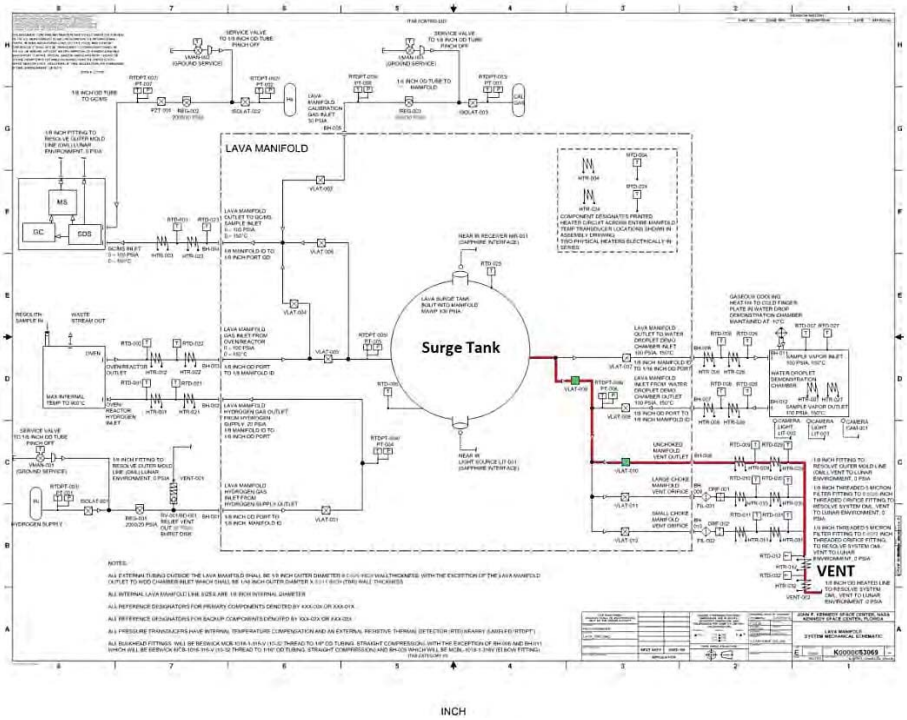

Figure 3. LAVA ETU Configuration Schematics. The Surge Tank evacuation flow to vent is highlighted with a red line and green valves indicating open valves that also animates on the LAVA interface during testing as they open.

The first operation is to remove the atmospheric gases that were trapped in the OVEN during sample insertion; called inert gas transfer. Once this is done, the sample will appear more like a real lunar sample. This is accomplished by flowing gases from the OVEN to the ST. The VML opens VLAT-005 to transfer inert gas to the ST for 1 minute then will close and delay for 30 seconds to record the pressures in PT-004 and PT-005 as shown in Fig.4. PT-004 (LAVA manifold hydrogen supply line pressure transducer [0-100psia]) is the pressure transducer used to measure the pressure in the OVEN. Note that PT-004 is located on the LAVA manifold since the OVEN becomes too hot for the PT. PT-005 (ST line A pressure transducer [0-100psia]) measures the pressure in the ST. The ST contents were sampled three times to estimate the amount of water being removed to ensure that it is consistent with room air humidity.

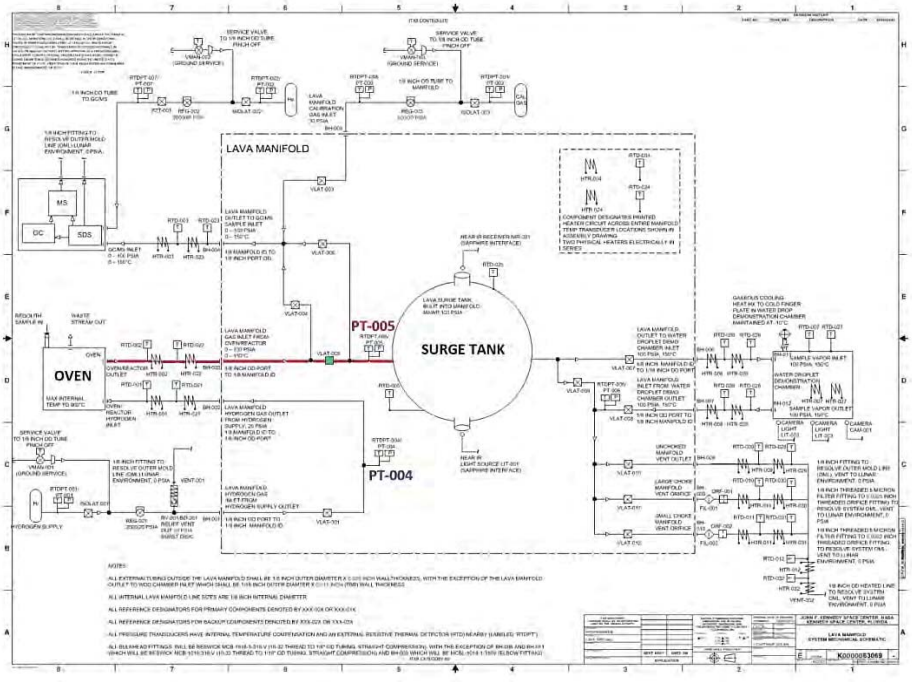

Figure 4. LAVA ETU Configuration Schematics. PT-004 located on the manifold measures the OVEN pressure and PT-005 measures the surge tank pressure. The red line indicates the flow of inert gas transfers that passes through VLAT-005 valve to get headspace samples from the OVEN to the surge tank.

Then after recording the pressures for PT-004 and PT-005, VML will evacuate the surge tank by opening VLAT-009 and 10 again for 2 minutes starting the inert gas transfer process again for two more times. This process will be repeated twice again giving 3 head space gas transfers as shown in Fig. 5. Each transfer results in a pressure decrease in the OVEN as the total amount of inert gas is reduced.

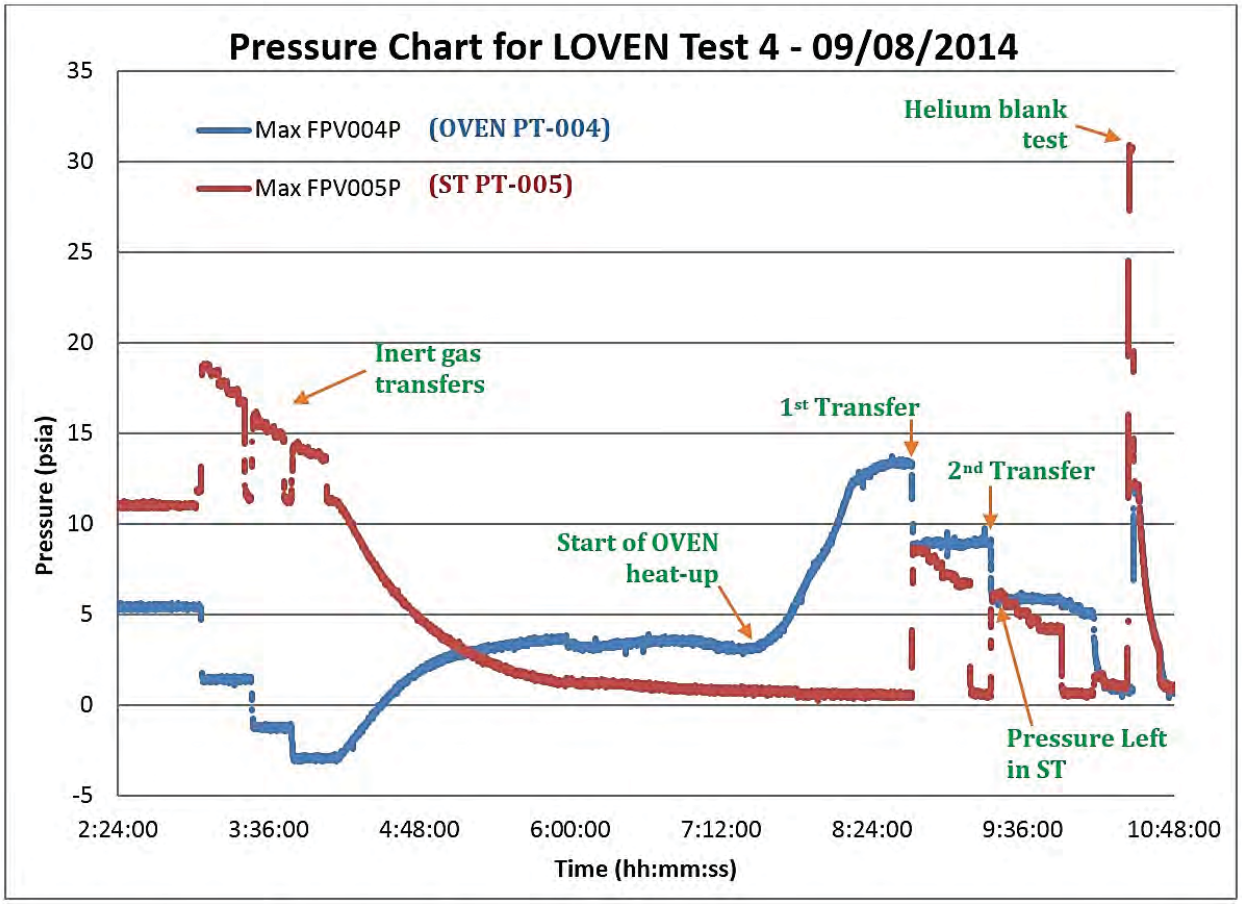

Figure 5. Pressure graph for LOVEN Test #4. This graph should have the same trend as LOVEN Test #1. Even though a regolith sample is present, they have the same amount of water present in them. This graph was used because the xGDS data collected also covered the inert gas transfers done earlier before the OVEN heat-up started and this headspace sampling wasn't done on the first LOVEN test.

After the inert gas transfer process which takes roughly about 12-13 minutes, the LAVA Warm-up can now commence. It roughly takes 2 hours for all the heaters to reach the set-point of 152°C which is the temperature that will drive off the gases of concern – water vapor, nitrogen, etc. The VML commands the heaters of OVEN to 152°C set point with the very bottom heater being set to 250°C. Once the OVEN has reached its setpoints, VML will open VLAT-005 after 3 minutes (time to stabilize the pressure) allowing transfer of sample from the OVEN to the surge tank for 30 seconds. PTs 4 and 5 pressures were recorded just before the transfer takes place and were recorded also after the transfer takes place (the pressure recorded here indicates how much sample is present at the surge tank). From here, following the same procedures VML has done, the users will have to do manual sample transfers since VML Full LOVEN Procedure was completed (the software was only made to last until the first transfer was made). The number of transfer will be decided by the users depending if they see consistent results for the GC-MS analysis. After all the transfers were made, a helium blank test will be made to evacuate the lines and the surge tank of any sample. This can be seen as a large pressure spike near the end of the test. The steps performed can be seen on the pressure graph below on Fig. 6 starting from the OVEN heat-up till the helium blank test.

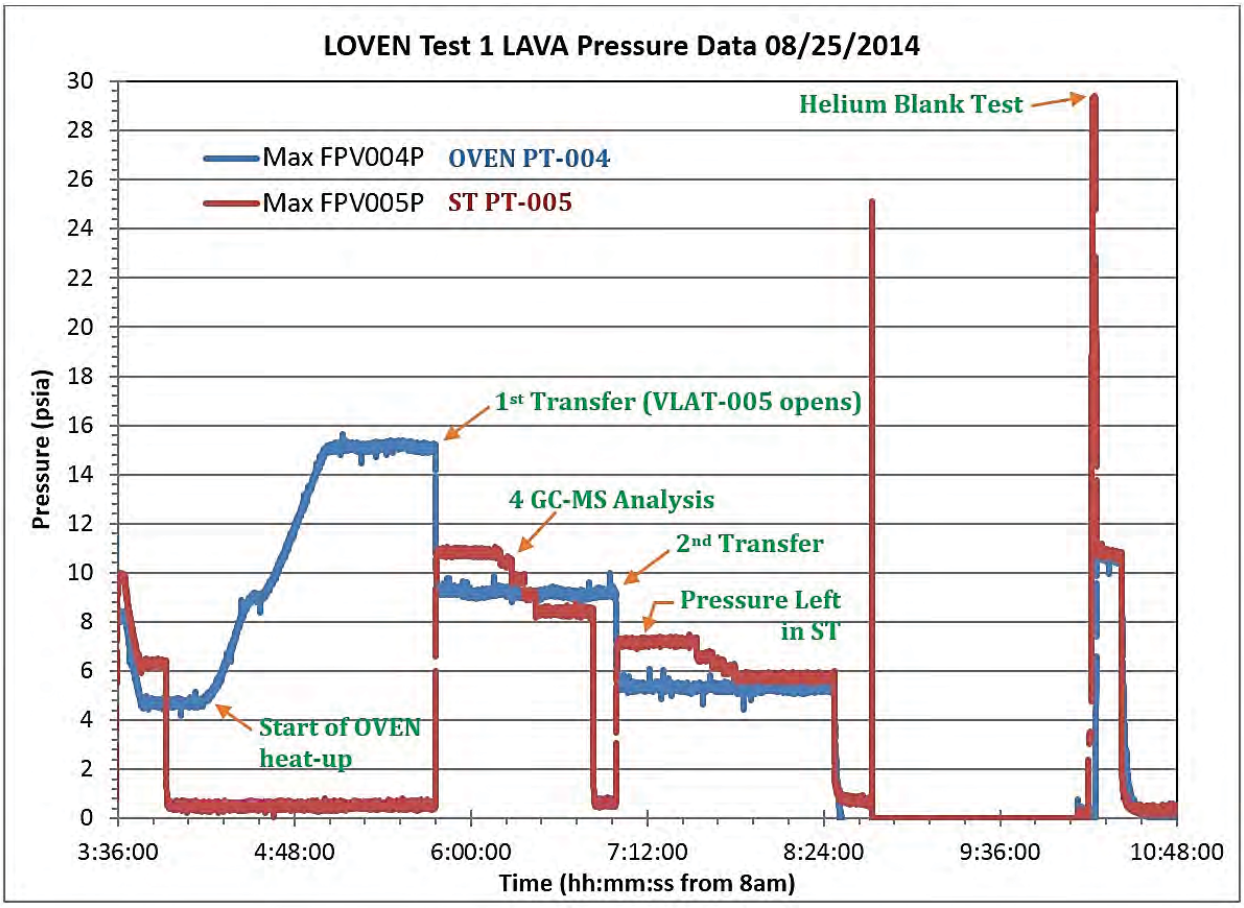

Figure 6. LOVEN Test #1 pressure plot. The major activities done during the test were labeled like the start of OVEN heat-up, transfers, and helium blank test.

III. Pressure Analysis for LOVEN Test #1

This section will outline the data analysis steps performed in the pressure analysis excel spreadsheet as applied to all LOVEN tests. We will use LOVEN test 1 as our example. There will be some different or additional steps on the tests with a regolith sample present in them. The first LOVEN Test contains 0.0649 grams of deionized water as a sample and was performed by conducting 2 transfers (2 big steps in the pressure chart) and 4 GC-MS analyses in each transfer (smaller steps within the big steps in the pressure chart). The chart and data sheet can be found on the LOVEN Test #1 excel sheet where the data was obtained from xGDS. Whenever there is a dip in the pressure, it means that a latching valve is being opened to allow a certain amount of transfer to take place for the analysis. The goal is to calculate everything based on moles so that the Ideal Gas Law can be applied and compare the analysis with the weighed water. The analysis begins with converting the weighed sample water from mass to moles by using the molecular weight of water.

A. Moles in OVEN (from weighed sample)

This was simply obtained by converting the mass of water (weighed) in OVEN from grams to moles by using the molecular weight of water.

Molecular weight of Water: $18.0153 \frac{g}{mol}$

Mass of Water in OVEN: $0.0649\ g$

therefore,

Moles in OVEN: $\frac{0.0649\ \cancel{g}}{18.0153 \frac{\cancel{g}}{mol}} = 0.0036\ mol$

The next step is to calculate the moles of Inert Gases in the OVEN before any transfer takes place. This will be used near the end of the analysis to more accurately determine the amount of water transferred from the OVEN to the surge tank.

B. Moles of Inert Gas in OVEN before Transfer at OVEN Temperature

Using the Ideal Gas Law (PV=nRT) and all implied assumptions, moles present in the OVEN were computed before any transfer was done.

Constants:

Gas Constant: $R = 82.05736 \frac{cm^3 \cdot atm}{K \cdot mol}$

Assumptions:

Volume in OVEN: $V_{OV} = 175\ cm^3$ (crucible empty space volume)

To obtain the temperature of OVEN, the average temperature range value for the FSS RTDs (MaxFTV001T-MaxFTV032T columns at the data sheet) at the beginning of the test (first rows) were used since none was heated yet, the OVEN and LAVA FSS should have the same ambient temperature.

Temperature of OVEN at the beginning: $T_{OV,initial} \approx 26°C = 299.15\ K$

To obtain inert gas pressure, subtract the pressure in OVEN before OVEN heating with the water pressure in OVEN before heating. The pressure in the OVEN before OVEN heating can be obtained when OVEN is at ≈ 26°*C* before pressure rise in the graph shown in Fig. 6 (this should be at a point when LAVA manifold is already at 152°*C*). The value for this pressure can be obtained from the Max FPV004P column in the data sheet (LAVA Manifold hydrogen supply line pressure transducer).

Pressure in OVEN before OVEN heating: $P_{OV,initial} = 4.720\ psia$

Water pressure in OVEN before heating, assuming saturated water vapor in OVEN (Water saturation table @ 26°*C*): $P_{sat,T@26°C} = 0.493\ psia$

$P_{inert} = P_{OV,initial} - P_{sat,T@26°C}$

$= 4.720\ psia - 0.493\ psia$

$= 4.227\ psia$

Using P_{inert}, the number of inert gas moles was calculated using the Ideal Gas Law:

$$n_{inert} = \frac{P_{inert} \cdot V_{OV}}{R \cdot T_{OV,initial}}$$

$$= \frac{4.227\ \cancel{psia} \frac{1\ \cancel{atm}}{14.7\ \cancel{psia}} \cdot 175\ \cancel{cm^3}}{82.05736 \frac{\cancel{cm^3} \cdot \cancel{atm}}{\cancel{K} \cdot mol} \cdot (26 + 273.15)\cancel{K}}$$

$$= 0.0021\ mol$$

Note: Temperature must be converted to *K*elvins (0°*C* = 273.15 *K*) and Pressure should be in *atm* (14.7 *psia* = 1 *atm*).

C. Moles transferred to the Surge Tank

Using the *Ideal Gas Law* (*PV = nRT*), the number of moles transferred to the ST were calculated after each transfer.

Constants:

Gas Constant: $R = 82.05736 \frac{cm^3 \cdot atm}{K \cdot mol}$

Assumptions:

Volume in Surge Tank: $V_{ST} = 100\ cm^3$

Average Temperature of the Manifold:

Temperature of ST (152°*C*): $T_{ST} = 425.15\ K$

The pressure used to determine the number of moles transferred was calculated by taking the pressure of ST after the transfer subtracted by the pressure in ST before the transfer. The pressure values were obtained from the Max FPV005P (PT-005, ST line A pressure transducer) after Max FVV008I (VLAT-005, ST latching valve 1 Pulse Time Talkback) closes (-2000 indication) and before VLAT-005 opens (2000 indication) respectively.

The following equation is used to determine the number of moles transferred into the ST for each transfer (where *i* = transfer number):

$$n_i = \frac{\left(P_{i_{after}} - P_{i_{before}}\right)_{ST} \cdot V_{ST}}{R \cdot T_{ST}}$$

❶ Calculating the number of moles in ST after the *first* transfer (please refer to LOVEN test #1 excel sheet for cell data obtained from xGDS to follow the procedures done):

Pressure in ST <u>before</u> the *first* transfer (cell F20717): $P_{1_{before}} = 0.495\ psia$

Pressure in ST after the *first* transfer (cell F20789): $P_{1_{after}} = 10.756\ psia$

Note: For the *first* transfer, Max FVV008I (VLAT-005) opened at cell AW20718 of the data sheet and closed at cell AW20788. This opening of the ST latching valve is where the pressures are being based from and can also be seen on the graph (big step) when the data point is referenced to the cell on the excel sheet graph. It can be observed that the valve was opened for 1 minute and 10 seconds (20788 – 20718 = 70 *s* for transfer time, this method is not consistent with all excel sheets though, the timestamp cells was used to compute the actual time, just relying on the cells is not appropriate because xGDS skips recording some time or data, so one cell doesn't necessarily mean 1 second).

$$n_1 = \frac{\left(P_{1_{after}} - P_{1_{before}}\right)_{ST} \cdot V_{ST}}{R \cdot T_{ST}} \quad \rightarrow \quad n_1 = \frac{(10.756 - 0.495)\ psia \frac{1\ atm}{14.7\ psia} \cdot 100\ cm^3}{82.05736 \frac{cm^3 \cdot atm}{K \cdot mol} \cdot (152 + 273.15)K} = 0.0020\ mol$$

The only parameter that changes after each transfer is the pressure, since it depends on the amount of gas sample present/left in the OVEN while retaining the same (ST) temperature of 152°*C*.

❷ Performing the same procedure for the *second* transfer:

Pressure in ST before the *second* transfer (cell F25133): $P_{2_{before}} = 0.706\ psia$

Pressure in ST after the *second* transfer (cell F26058): $P_{2_{after}} = 7.075\ psia$

Note: For the *second* transfer, Max FVV008I (VLAT-005) opened at cell AW25134 and closed at cell AW26057. This opening of the ST latching valve is where the pressures are being based from and can also be seen on the graph (second big step, lower pressure than the first big step of the first transfer) when the data point is referenced to the cell on the excel sheet graph. The pressures kept on decreasing from the moment the first transfer was done since the sample is not evolving anymore. Meaning, there is no more water becoming vapor to add more pressure in the OVEN.

$$n_2 = \frac{(7.705 - 0.706)\ psia \frac{1\ atm}{14.7\ psia} \cdot 100\ cm^3}{82.05736 \frac{cm^3 \cdot atm}{K \cdot mol} \cdot (152 + 273.15)K} = 0.0012\ mol$$

◉ The Total Moles Transferred to ST for LOVEN Test #1 is determined by following the equation below (cell M32):

$$n_1 + n_2 = 0.00200091\ mol + 0.001241779\ mol \approx 0.0032\ mol$$

D. Moles Left in OVEN

This is obtained based from the Pressure Left in OVEN. Ideally, the Pressure in the ST after the last transfer (after closing the valve for the last transfer before any GC-MS analysis takes place) should be equal or within 1 psia of the pressure left in OVEN.

The pressure transducer of OVEN (PT-004) for this particular LOVEN test #1 wasn't calibrated well, therefore, it was determined that the ST pressure transducer (PT-005) was more accurate. When VLAT-005 is opened, OVEN and ST pressures come together and equilibrate (OVEN pressure drops and ST pressure rises because the line between them is opened to allow transfers to partake: OVEN → ST). Therefore, the pressure left in the OVEN is observed to be:

Pressure Left in OVEN (assumes PT-004=PT-005): $P_{OV,remnant} = 7.075\ psia$

To obtain the **temperature of OVEN**, the helium blank test performed at the end of the LOVEN test was used.

a. The opened VLAT-005 at the helium blank test was taken into account. This can be seen on Max FVV008I column (MSID label for **S**urge **T**ank latching valve 1 Pulse Time Talkback) 2000 indication (VLAT-005 opening) on cell AW36880. This should correspond around the same time of the pressure peak (highest pressure value) of the red plot (ST) on the graph labeled on Fig. 6.
b. The average pressure in the ST (Max FPV005P column: PT-005, ST line A pressure transducer) was obtained before VLAT-005 was opened. This can be seen computed on cell H36880 with the value of 29.18 *psia*.
c. Moles in the ST is computed at the average pressure:

   where Volume in ST: $V_{ST} = 100\ cm^3$

   Temperature of ST (152°*C*): $T_{ST} = 425.15\ K$

Average pressure before opening VLAT-005 in the helium blank test obtained at b.: $P_{STHe,avg}$: 29.18 *psia*

$$n_{STHe} = \frac{P_{STHe,avg} \cdot V_{ST}}{R \cdot T_{ST}}$$

$$= \frac{29.184312\ psia \frac{1\ atm}{14.7\ psia} \cdot 100\ cm^3}{82.05736 \frac{cm^3 \cdot atm}{K \cdot mol} \cdot (151 + 274.15) K}$$

$$= 0.0057 \text{ mol}$$

d. Temperature can now be determined using $P_{ST,beforeVac} V_{ST+OVEN} = n_{STHe} R T_{OV}$

$$T_{OV} = \frac{P_{ST,beforeVac} \cdot V_{ST+OVEN}}{n_{ST,He} \cdot R}$$

The Pressure is the average stable pressure of ST for the helium blank test before completely opening the valve to vacuum at the very end of the test (located on cell H36881): $P_{ST,beforeVac}$ = 10.8635 *psia*

therefore,
$$T_{OV} = \frac{10.86352872\ psia \frac{1\ atm}{14.7\ psia} \cdot (100+175) cm^3}{0.00569 \text{ mol} \cdot 82.05736 \frac{cm^3 \cdot atm}{K \cdot mol}}$$

Temperature of OVEN during transfers: T_{OV} = 435.2074634 *K*

$\frac{P_1 V_1}{T} = \frac{P_2 V_2}{T}$ was used where V_2 is the total volume for both OVEN + ST

One of the issues were have is that the OVEN temperature is actually a composite of a variety of heater temperatures. We would like to know the effective temperature of the OVEN, in other words the temperature that the OVEN appears to have based on its volume and pressure.

Using the remaining pressure, the calculated OVEN temperature and the *Ideal Gas Law* (*PV = nRT*), the Moles Left in OVEN are calculated:

$$n_{OV,remnant} = \frac{P_{OV,remnant} \cdot V_{OV}}{R \cdot T_{OV}}$$

$$= \frac{7.075\ psia \frac{1\ atm}{14.7\ psia} \cdot 175\ cm^3}{82.05736 \frac{cm^3 \cdot atm}{K \cdot mol} \cdot 435.2074634\ K}$$

$$= 0.0024\ mol$$

E. Total Moles Measured in OVEN+ST

This is simply the summation of the moles computed in part C and D of the analysis.

	Total Moles Transferred to ST (part C):	0.0032 *mol*
+	Moles Left in OVEN (part D):	0.0024 *mol*
		0.0056 *mol*

F. Total Moles Measured in OVEN + ST minus inert gas moles

This is simply the subtraction of part B from part E of the analysis.

	Total Moles Measured in OVEN+ST (part E):	0.0056 *mol*
–	Moles of Inert Gas in OVEN before Transfer (part B):	0.0021 *mol*
		0.0036 *mol*

The moles of gas are converted to grams for comparison with the mass of the weighted sample.

Molecular weight of Water: 18.0153 $\frac{g}{mol}$

Moles Measured in OVEN + ST minus inert gas moles (Part F., water vapor only): 0.0036 *mol*

therefore, Mass of Water in OVEN: 0.0036 ~~*mol*~~ · 18.0153 $\frac{g}{\sout{mol}}$ = 0.0640 *g*

So, taking the original mass of the weighed sample and comparing it to this number, we calculate the mass difference between the actual mass and the analyzed mass obtained from the data generated by the instruments.

Mass of Water in OVEN (weighed): 0.0649 *g*

Mass of Water in OVEN (instrument-analyzed): 0.0640 *g*

Mass Difference: $\frac{0.0640 - 0.0649}{0.0649} \cdot 100$ = -1.42 %

And if the Expected Loss during transfer was also accounted for this mass difference, the difference would even go down further to:

Expected Water Loss from transfer into OVEN: 0.001 *g*

Mass Difference with Expected water loss accounted for: $\frac{0.0640+0.001-0.0649}{0.0649} \cdot 100 = 0.12\%$

This demonstrates a mass difference of almost zero. Of course, there would be a discrepancy in terms of rounding off and other cause for loss like sample sticking on the lines during transfer and such. But, this analysis proved to be effective and the instruments working the way they're supposed to. Trade studies for the materials needed for more flight forward instruments are still ongoing.

A difference in two of the LOVEN tests performed would be the OVEN volume. LOVEN tests 4 and 5 contain a solid sample in them. Otherwise, the other procedures were also followed and applied to the all LOVEN tests. The Volume in OVEN is different because there is a simulant present in the crucible (regolith sample JSC-1A) which takes up space, therefore, the headspace volume will also be different (less than the usual assumption of $V_{OV} = 175\ cm^3$). To obtain the Volume in OVEN, the Volume of JSC-1A with 20 grams was taken into account. The density for JSC-1A was found out to be 1.7 $\frac{g}{cm^3}$. So, converting this to volume in order to subtract it from the volume of an empty crucible would give:

$$V_{\text{JSC-1A,20g}} = \frac{20\ \cancel{g}}{1.7\ \frac{\cancel{g}}{cm^3}} = 11.76\ cm^3 \approx 12\ cm^3$$

then

Volume in OVEN:

	$V_{\text{OV,empty}}$	$175\ cm^3$
$-$	$V_{\text{JSC-1A,20g}}$	$12\ cm^3$
	V_{OV}	$163\ cm^3$

therefore,

Volume in OVEN (with regolith): $V_{OV} = 163\ cm^3$

The other LOVEN tests also gave a very small percentage of mass difference. Another test, the NIRST analysis, was compared to this pressure analysis which also gave a small error percentage with this analysis. This shows that the concept of Ideal Gas Law proved to be effective for the analysis and the instruments are ready for a more flight forward design.

IV. Conclusions

This internship truly expanded my knowledge and skills in the world of Space Science, with a bonus of experiencing the breath-taking launching of space crafts. NASA has given me an opportunity to work with a remarkable team of individuals who supported me in every step of the way. I am very honored to work for the RESOLVE team and hope for the project's success. Imagine if we could harness all the resources on the moon and prove that it could be effectively used for space human exploration systems: it would minimize the materials carried from Earth, it will provide life support, propellants construction materials and supply energy to the payload or crew. Although we are now living in a world of developing technology, demographic changes, and transition of many government policies, we should not be affected by these stressors. Instead, let us unite and begin a positive change towards a productive country – to bring back United States of America in the limelight of advance technology through research and development and make the Earth a better place to live.

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VI. References

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